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The Circulation over the Continental Shelf South of Cape Hatteras

by

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APPROVED FOR DISTRIBUTION ____________
Director

The Circulation over the Continental Shelf South of Cape Hatteras

The waters of the continental shelf of the United States south of Cape Hatteras (Fig. 1) have received, until recently, exceedingly little attention compared with the shallow and slope waters to the north. Prior to 1948 the oceanographic data from this region comprised occasional observations by Bigelow, one section by Iselin (1936), some current measurements by the U. S. Coast and Geodetic Survey alluded to by Rude (1922), and those reported by Haight (1942).

The only discussion of the oceanography of the region lies in a recent summary by Marshall (1950), but that deals mostly with the waters of the sounds. Toumey in the Geological Survey of South Carolina for 1848 described "an eddy current which washes the coast southwardly" (Gulliver, 1896). Backset eddies driven by the Florida Current have been considered as responsible for the cuspate form of the coast line by Abbe (1895), Gulliver (1896), Davis (1912), and Shepard (1948). Rude (1922), on the basis of current measurements in the winter of 1915-16 and 1916-17, does not accept the theory of backset eddies. He found superimposed on the rotary tidal current "a set with the local wind prevailing at the time of observation". Parr (1933) noted the winter temperature barrier which occurs at Cape Hatteras. Pierce (1953) demonstrated that the distribution of chaetognaths was directly related to the water masses in the area.

One of the characteristic features of the hydrography of continental shelf waters is a dynamic coastal current induced by the addition of fresh river runoff water at the coast. The southerly flowing current along the eastern seaboard of the United States north of Cape Hatteras is an example. Part of this current manifests itself near the coast as a slow drift of 3 to 20 miles per day (Miller, 1952), but most of the transport is near the 100-fathom contour where it does not have to overcome bottom friction.

It has become evident from recently collected data south of Cape Hatteras that a southerly flowing coastal current in that region does not always exist. Certainly, one can never exist along the 100-fathom line inasmuch as the Florida Current lies just a few miles from the 100-fathom line, and waters over the edge of the shelf are subject to the frictional drag of this great stream.

There appear to be several reasons why a dynamic coastal current is a transient affair in this region:

1. Raleigh Bay and Onslow Bay receive no regular contribution of freshened water or southerly flowing water from north of Cape Hatteras. Hence there is no continuity with the waters north of Cape Hatteras.

As will be noted in 2 below the fresh-water contribution from the rivers is small and mixed with sea water. If the runoff into this region were comparable to that of Chesapeake Bay a coastal current would be assured of a healthy inception.

2. River water contributions per unit length of coast line are on the average less than one half as great as for any other section of the coast. Table I presents comparative mean runoff data for the several drainage basins along the eastern seaboard. It is apparent that the runoff per unit area for the Carolina region is not, on the average, significantly less than for the other regions, but the runoff per unit length of coast line between Cape Hatteras and the South Carolina border, i.e. of the Pamlico, Neuse, and Cape Fear River basins, is very small, being 1.9 m^3 per sec. per km., as compared with an average of 5.2 m^3 per sec. per km. for all the other sections of the coast. Further, the effluent from the rivers becomes well mixed with sea water in the estuaries and sounds so that the water entering the sea through the inlets is no longer very fresh*. For instance, salinities observed at Hatteras and Ocracoke Inlets ranged from 28.5 to 35.5 $^o/oo$ (Roelofs and Bumpus, 1953), at Beaufort Inlet from 18 to 35.4 $^o/oo$ (Sutcliffe, 1951), but generally tending toward salinities greater than 32 $^o/oo$. Lower salinities are always found at the mouths of the Hudson River, Delaware Bay, and Chesapeake Bay. As a result the salinity gradient is greater next to the coast off the northern shores than in Raleigh or Onslow Bays.

3. The temperature gradient across the continental shelf during the winter months is more than sufficient to counteract the salinity effect on the pressure gradient during periods of average runoff, thus dynamically providing for a northerly set to the coastal waters.

4. Due to the geography of the coast line the southwesterly wind, which is the prevailing wind during many months of the year, blows parallel to the general direction of the coast south of Cape Hatteras, whereas from Hatteras to New York it is an offshore wind. This wind with a relatively long fetch at

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* Mixing in the Cape Fear River may not be as complete as in the other estuaries in the region.

Table I

Mean Runoff Data for Several Drainage Basins along Atlantic Seaboard of U.S.

Drainage Basin	Runoff $m^3/sec/km^2$	Drainage Area km^2	Runoff m^3/sec	Coast Line km	Runoff $m^3/sec/km$
Hudson River	0.017	34618	588	135	4.35
Delaware River	0.019	36001	684	136	5.02
Chesapeake Bay	0.013	173979	2261	244	9.3
Albermarle Sound	0.012	43019	516	67	7.7
Pamlico to Cape Fear River	0.011	61981	682	352	1.9
Peedee, Savannah & Altamaha Rivers	0.012	198430	2380	485	4.9

Long, Onslow, and Raleigh Bays serves to retard or deflect offshore any south flowing coastal current.

5. Further, this southwest wind will pile up water on the south sides of the capes creating an hydraulic current which tends to flow offshore over the projecting bars. This hydraulic current will deflect offshore any southerly flowing coastal current approaching the cape on the lee side, and, through turbulence, will mix it with more saline water, thus preventing augmentation of the current from one river mouth to the next. (This opposition of currents at the cape tips may indeed provide the mechanism which helps to maintain the capes, inasmuch as the velocities may be reduced there and the heavier elements of the sediment loads dropped).

6. Finally, the proximate Florida Current produces a frictional drag on much of the water over the continental shelf, which drag a coastal current must overcome.

Thus it appears that a southerly flowing coastal current will not prevail during the winter months unless the runoff is exceptionally great. At other times of the year such a current will depend primarily on the amount of runoff and secondarily on the wind direction, force, and duration.

The following observations are presented in support of this hypothesis.

Runoff Data

Figure 2 shows the runoff for the period October 1947 to September 1953 and the times when the cruises to collect the hydrographic data to be discussed were made. We see that immediately prior to RELIANCE Cruises 4 and 6 the runoff had been four times greater than the mean but was diminishing rapidly. Prior to CARYN Cruise 7 and ALBATROSS III Cruises 18-19 the runoff had been well above the mean for several months but had dropped to near mean values. Prior to ALBATROSS III Cruises 30 and 32 runoff averaged less than the mean for several months. Prior to CARYN Cruise 64 runoff had been twice the mean but had since diminished. These runoff trends are reflected in the salinity distribution over the continental shelf and hence contribute to the distribution of the dynamic pressure gradient.

Drift Bottles

Two sets of drift bottles (with and without drags) were released in the North Carolina area, one set in January and the other in February and early March, 1950, ALBATROSS III Cruises 30 and 32.

The first set comprised 816 bottles released at 51 positions, 16 bottles at each position. Forty-six bottles have been recovered from 17 of the positions as indicated in Table II and Figure 3.

TABLE II

Drift Bottles Recoveries from ALBATROSS III - Cruise 30

Station	Recovery Position		Days Adrift	Remarks
4	35-15	75-31	2)	12 miles per day
	35-14.5	75-31.3	2)	
	35-02	75-59	2)	
	25-16.9	75-31	6)	
9	Azores		218	
15	Portugal		753	
17	Cape Lookout		21)	
	" "		23)	0.6 miles per day
	Shackleford Beach		91)	
	" "		91)	
18	Cape Lookout and Shackleford Bank (7 bottles)		23	1.2 miles per day
	Atlantic Beach		54	0.4 " " "
	Cape Hatteras		114	0.8 " " "
	Cape Lookout		181	
	" "		352	
22	Azores		255	
24	Shackleford Beach		17	2.5 " " "
25	Atlantic Beach near Ft. Macon		26	2 " " "
	Shackleford Beach		66	
	W. Beaufort, N. C.		85	up the estuary
	Spain		444	
29	Cape Hatteras		81	1.6 miles per day

Station	Recovery Position	Days Adrift	Remarks
30	France	823	--
33	England	891	--
35	Eleuthera	327	--
37	Spain	434	--
40	Azores	265	--
41	Bermuda	83	--
	Canary Islands	424	--
42	Cape Lookout	88	70 miles in 88 days, 0.8 miles per day
45	Cape Lookout	1*	4.5 miles per day
	Cape Lookout	15-88**	

* 4 bottles ** 6 bottles

The second set comprised 490 bottles released at 49 stations, 10 at each station. Twenty-four of the bottles have been returned from 15 of the positions, as indicated in Table III and Figure 4.

TABLE III

Drift Bottle Recoveries from ALBATROSS III - Cruise 32

Station	Recovery Position	Days Adrift	Remarks
1	Shackleford Beach to Cape Lookout	18-24*	0.25 mi./day
3	Ocracoke	276	0.42 mi./day
10	Ocracoke	108	1.2 mi./day
	Azores	254	--
12	Azores	165	--
14	Avon Beach	102	1.5 mi./day
15	Eire	659	--

Station	Recovery Position	Days Adrift	Remarks
22	Core Beach	39	1.5 mi./day
26	Core Beach	16	1.9 mi./day
28	Shackleford Beach	59-74**	0.2 mi./day
30	British West Indies	751	--
36	Canaries	487	--
39	Ocracoke to Hatteras	5-110*	1 mi./day
	Azores	313	--
41	Canaries	424	--
43	Azores	142	--
47	Bermuda	347	--

* 4 bottles   ** 2 bottles

These drift bottle recoveries indicate a definite north-easterly movement of the surface coastal waters during January-March, amounting to from 0.2 to 12 miles per day. It is also apparent from the foreign returns and from the bottles conspicuous by their absence that the movement tends somewhat offshore rather than onshore. These drifts are compatible with that indicated by the hydrographic conditions for the same period, a period of less than mean runoff.

Two of Miller's (1952) bottles launched in the offing of Cape May in May, 1951, stranded on the shores of Raleigh Bay, having moved southerly around Cape Hatteras presumably during the five days of easterly winds, 15 to 20 June. These are the only bottles on record to have rounded the Cape in that direction or, for that matter, to have been recorded as moving southerly in this region.

Temperature, Salinity, and Density Distribution

The temperature and salinity data were collected in the course of eight cruises:

19-25 March	1948	RELIANCE	Cruise 4
26 April-1 May	1948	"	" 6
13-15 May	1949	CARYN	" 7

20-25 May	1949	ALBATROSS III	Cruises 18-19
8-13 January	1950	" "	Cruise 30
25 February-4 March	1950	" "	" 32
13 May	1953	CARYN	" 64
9-10 June	1953	"	" 64

Typical sections across Onslow Bay, Figures 5, 7, 9, 11, 13, 15, 17, and 18, diagram the distribution of temperature, salinity, and density in profile. The distribution of these same properties at the surface in Long, Onslow, and Raleigh Bays is illustrated in Figures 6, 8, 10, 12, 14, and 16. From the two sets of figures a general idea of the hydrography of the area may be obtained. The conditions peculiar to the several times of observation are summarized below.

January 8-13, 1950; ALBATROSS III - Cruise 30 (Figs. 5 and 6)

Strong horizontal temperature gradients but minimal vertical temperature gradients were characteristic of the shelf waters in January 1950. The salinity distribution tended to be similar to the thermal structure although the relatively small runoff during the preceding weeks accounts for the absence of lowered salinity next to the coast. Water of salinity greater than 36 ‰ had penetrated at all depths well across the shelf to within ten miles of the coast on the average. Density decreased from the coast seaward in Onslow and Raleigh Bays. This was due to the temperature increase seaward and the insufficiency of freshened water next to the coast to counteract the temperature effect. Hence the density structure suggests the absence of a countercurrent and a slow northerly drift all across the shelf. South of Cape Fear a southerly coastal drift is indicated. The northerly drift over the shelf was substantiated in the drift bottle experiment described above.

February 1950; ALBATROSS III - Cruise 32 (Figs. 7 and 8)

The temperature and salinity structure for this period was very similar to that observed during the previous month. The effect of lower than normal runoff allowed the intrusion of highly saline water even closer to the coast than earlier. The north-northwest wind which prevailed during the month appears to have pushed water from Pamlico Sound out through Hatteras and Ocracoke Inlets, freshening and cooling the water in their offings. Again the temperature effect on density produced a decrease in density with distance offshore at all depths, suggesting a northward drift of all the water over the shelf. The nascent coastal current south of Cape Fear was less well developed. The drift bottle experiment conducted during this cruise also gave supporting evidence for a northerly drift of all the shelf waters in this region.

March 19-25, 1948; RELIANCE - Cruise 4 (Figs. 9 and 10)

In March 1948 the temperature and salinity distribution differed from the January and February conditions of 1950 due in part to the vernal warming, but chiefly to the preceding large runoff from the adjacent watershed. Water of salinity greater than 36 $^{o}/_{oo}$ lay over the outer one-third of the shelf, the inner two-thirds being occupied by effluent water of less than 33.5 $^{o}/_{oo}$ minimum in Onslow Bay and less than 31.5 $^{o}/_{oo}$ minimum in Raleigh Bay. Temperature increased with depth as did salinity due to the flooding of the colder effluent out over warmer more saline shelf water. These conditions combined to produce a slight vertical density gradient with maximum densities at all depths occurring over the central part of the shelf, with lowered densities offshore and still lower densities inshore. These dynamic conditions should produce a weak southerly coastal current over the inner part of the shelf. The winds were predominantly from the northeast during the preceding month and a half. The southwest wind blowing at the time the observations were made in the northern part of Raleigh Bay served to move a thin layer of the Pamlico Sound water from Hatteras and Ocracoke Inlets offshore over more saline water.

April 26 - May 1, 1948; RELIANCE - Cruise 6 (Figs. 11 and 12)

Although the observed salinity measurements were not as low in April as during the preceding month it is apparent that the previous large accumulation of low salinity water and the continued greater than mean runoff was more uniformly distributed over the inner part of the shelf due to the prevailing southwest wind during April. Horizontal and vertical gradients were weaker than during the previous month. A slight horizontal density gradient prevailed throughout the area with the maximum at all depths over the center of the shelf in Onslow Bay, but closer inshore in Raleigh Bay. This indicates a weak southerly coastal current inshore of this low and a northerly drift offshore parallel to the Florida Current.

May 13-15, 1949; CARYN - Cruise 7 (Figs. 13 and 14)

No observations were made in Raleigh Bay during CARYN Cruise 7 nor were those in Onslow Bay well distributed. They do serve, however, to demonstrate the tendency at this time for a thermocline to develop, although it was very weak over the inner one-third of the shelf. The intrusion of considerable runoff augmented the stability, although the vertical salinity gradient was weak. There appears from the density structure to be a weak southerly current although there may be a weaker northerly current inshore if it. The prevailing southwest wind during the preceding month may have served to move the coastal current and attendant freshened water slightly offshore. The outer one-third of the shelf was occupied by virtually isothermal, isohaline Florida Current water.

May 20-25, 1949; ALBATROSS III - Cruises 18 and 19 (Figs. 15 and 16)

Little change in the vertical structure since the cruise a few days earlier is evidenced in this data. During this cruise, with somewhat better coverage of the area than CARYN Cruise 7, Raleigh Bay was virtually flooded with high salinity water, $S > 36$ ‰, whereas freshened water, $S < 35$ ‰, tended offshore in the southern part of Onslow Bay. A density high occurred over the central part of Onslow Bay with an appreciable gradient toward the shore, especially in the northern part of Long Bay. This suggests the development of a moderately healthy, southerly flowing coastal current commencing in Onslow Bay, being augmented in Long Bay by the Cape Fear River.

May 13, 1953; CARYN - Cruise 64 (Fig. 17)

A single section across the center of Onslow Bay provides data for May 1953. The waters are slightly more stratified than on the 1949 cruises in May, apparently due to the intrusion of cold, highly saline water across the shelf on the bottom. On this is superimposed freshened water from the relatively high runoff during March and April. The temperature and salinity distribution have tended to reinforce each other in the production of a rather stable density structure. The density distribution suggests a slight southerly coastal current down the center of Onslow Bay with a slight northerly countercurrent inshore. Such motions can only serve to further dilute the river effluent and weaken the coastal current. This appears to be borne out in the June 1953 data.

June 9-10, 1953; CARYN - Cruise 64 (Fig. 18)

One section across Onslow Bay and one across Raleigh Bay comprise the June 1953 data.

Since May 1953 the water had increased in temperature at all depths over the inner half of the Onslow Bay shelf. The decreased runoff since April together with rather complete mixing and dispersion of freshened water with shelf water are reflected in the increased salinity of the surface waters. The intrusion of water with a salinity greater than 36 °/oo had receded. The temperature and salinity distribution have combined to continue to produce a rather stable density distribution. The coastal current had degenerated to a very weak affair.

From these examples of the hydrographic structure of the shelf waters in Onslow Bay it is apparent that the over-all picture is much more simple than that over the shelf north of Cape Hatteras. The shallow depths, the short distance from the coast to the continental edge, the swift Florida Current flowing along that edge serve to permit the transfer of runoff through the area at a rather rapid rate. Winds and the rotary tidal currents in the shallow waters increase mixing and resist the development of strong density gradients.

Fresh-Water Content

Estimates of the fresh-water content on the continental shelf on the several occasions have been made by planimetering the areas between the isohalines on the salinity sections, Table IV. Sea water salinity was assumed to be 36.0 °/oo.

It is clear from Table IV and is quantitatively indicated that the volume of fresh water contained in the waters over the North Carolina shelf varies from time to time by more than a factor of 10. It is also clear that the fluctuations in fresh-water volume are associated with the gross sustained fluctuations in runoff. We have not been able to derive a satisfactory relationship between the fresh-water volume and the runoff for a short period.

We conclude that the removal of water from the Carolina shelf is not steady, but is perhaps modified by the wind systems and modulations in the flow of the adjacent Florida Current (von Arx et al., 1954). A southwest wind will deflect the freshened water offshore into the frictional drag of the Florida Current where it will be quickly removed. The Florida Current may encroach, either along the bottom where it displaces water at that depth and forces freshened water off at

TABLE IV

Fresh-water content of Carolina shelf waters

	% of total volume*			Fresh-water vol. $\times 10^{10} m^3$			
	Raleigh	Onslow	Long	Raleigh	Onslow	Long	Total
January 1950 ALBATROSS III - 30	0.14	0.10	0.20	0.030	.047	.034	0.111
February 1950 ALBATROSS III - 32	0.02	0.10	0.11	0.004	.051	.019	0.074
March 1948 RELIANCE - 4	0.63	1.63	0.80	0.133	.800	.137	1.070
April 1948 RELIANCE - 6	0.19	1.09	0.97	0.041	.534	.166	0.740
May 1949 CARYN - 7	--	0.44	0.78	--	.214	.134	--
May 1949 ALBATROSS III - 18,19	0.00	0.75	1.28	0.000	.368	.220	0.588
May 1953 CARYN - 64	--	1.43	--	--	.704	--	--
June 1953 CARYN - 64	0.21	1.53	--	0.044	.751	--	--

* Total volume to 100 fathom line, Raleigh Bay 21.15 x $10^{10} m^3$, Onslow Bay 49.11 x $10^{10} m^3$, northern part of Long Bay 17.16 x $10^{10} m^3$, grand total 87.42 x $10^{10} m^3$.

the surface, as was observed to occur on another part of CARYN Cruise 64. Or it may move in bodily at all depths sweeping coastal water out of the area, presumably to the north where it becomes part of the Gulf Stream or slope water*. Light winds which produce no great frictional effect and onshore winds will permit fresh water to accumulate on the shelf. These influences make it possible for fresh water to diminish with increasing runoff or to accumulate on the shelf with a falling runoff. But from the over-all point of view, high sustained runoff produces a large relative volume of fresh water on the shelf (e.g., March 1948) and a low sustained runoff yields a relatively low fresh-water volume.

Summary

The hydrography of the continental shelf off North Carolina, south of Cape Hatteras, is controlled by an environment which produces moderate horizontal gradients and weak to moderate vertical gradients in temperature and salinity. In winter water temperatures may range from 10°C. at the coast to 22°C. only 60 miles to the southeast. Salinity in the sounds, bays, and rivers is as low as 18 °/oo, approximately 32 °/oo at the inlets, yet a salinity of 36 °/oo may occasionally be found within 10 miles of the coast and never further than 50 miles away. Gradient conditions are greatest in Raleigh Bay, less strong in Onslow Bay, and least in Long Bay, due chiefly to the geography; i.e., the continental shelf widens toward the southwest. The seasonal progression of temperature and salinity distribution may frequently be modified by intrusions of the Florida Current over the continental shelf. This intrusion may be especially broad in Raleigh Bay.

Nontidal currents over the shelf may be so slow that they are barely detectable, yet just over the edge of the continental shelf the Florida Current ceaselessly flows at speeds greater than 150 cm/sec. Six reasons why a dynamic coastal current is a transient affair in this region are given. The nontidal currents over the inner parts of the shelf appear to result from the balance of forces at work, tending northerly in general but turning southerly when the pressure gradient

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* Surface observations at Diamond Shoals Lightship over a period of nearly six years reveal large, and frequently sudden, fluctuations in the water temperature due to the passage to and fro of the interface between the colder waters from north of Cape Hatteras and the waters of Raleigh Bay influenced by the Florida Current. Meander-like encroachments onto the shelf and recessions from it of the Florida Current appear to be one of the logical explanations for these fluctuations. Correlations with wind direction and force are patently unsatisfactory. Yet northeast storms are effective in driving Middle Atlantic coastal water southerly across Diamond Shoals.

is modified sufficiently by the runoff to counteract the thermal effect, or the frictional drag of the southerly winds or the Florida Current.

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List of Figures

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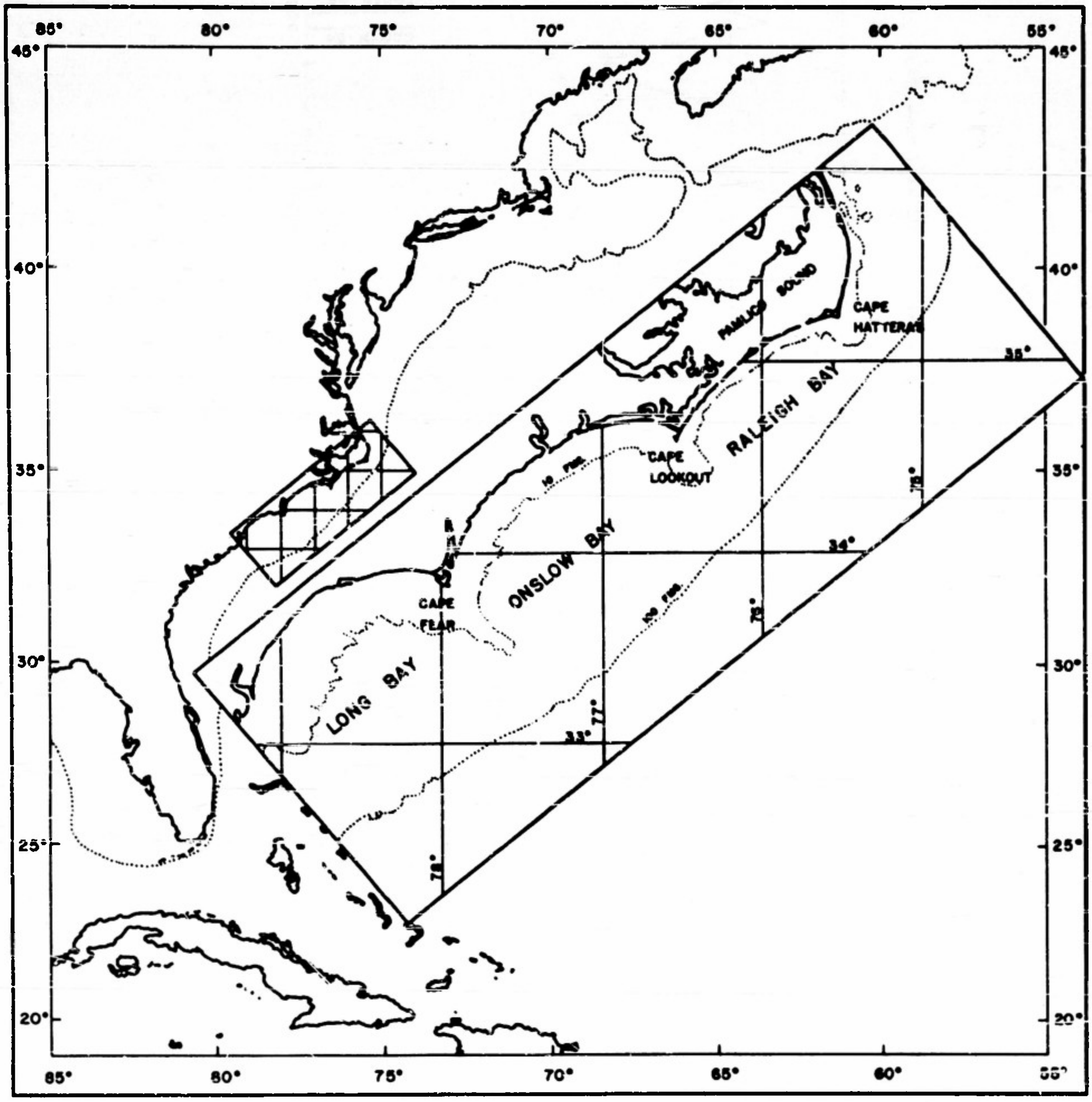

FIGURE 1. CHART OF EAST COAST OF U.S. WITH INSET INDICATING AREA UNDER DISCUSSION.

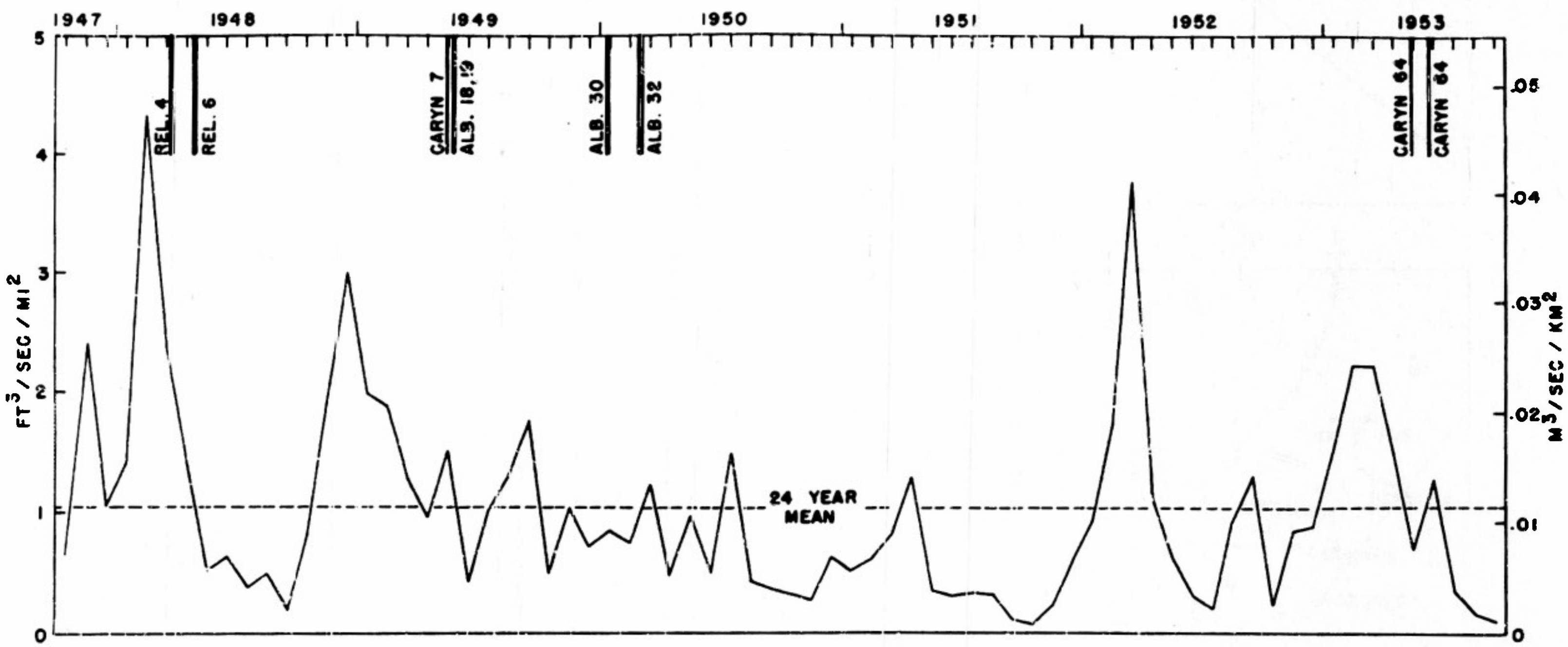

FIGURE 2. RUNOFF FOR THE PERIOD OCTOBER 1947 TO SEPTEMBER 1953 FROM PAMLICO, NEUSE, AND CAPE FEAR RIVER BASINS.

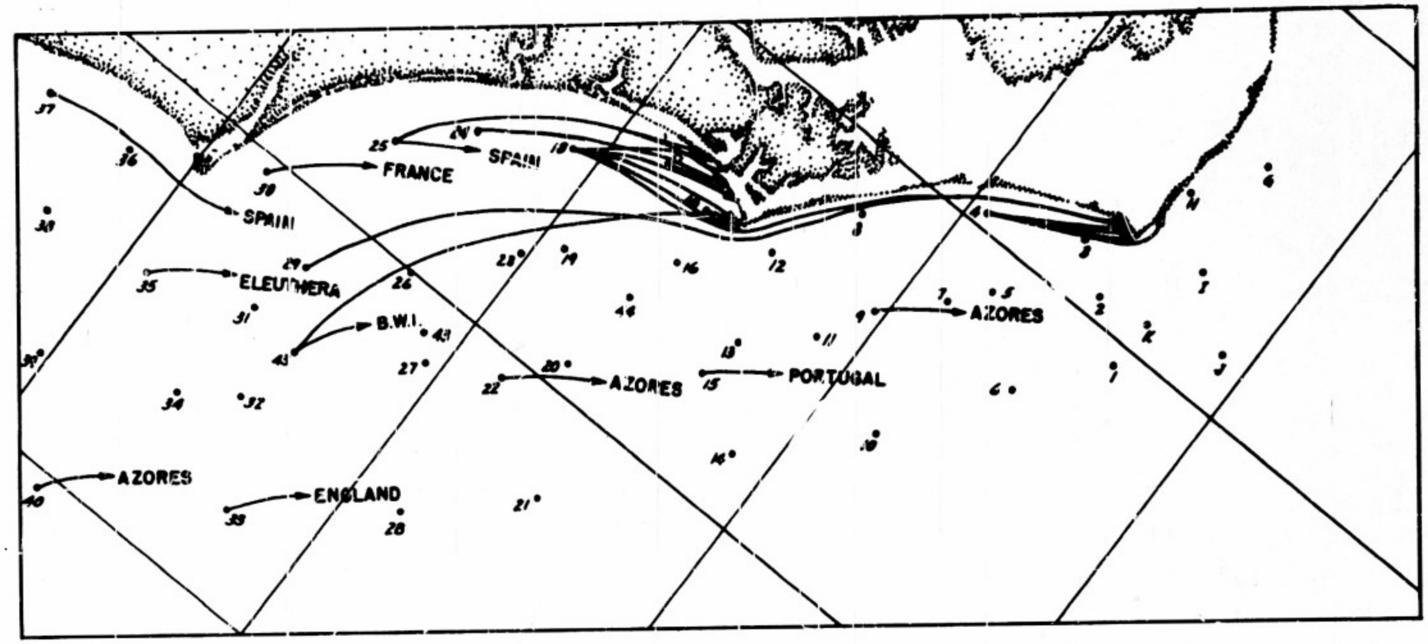

FIGURE 3. ROUTES OF DRIFT BOTTLES RELEASED 9-13 JANUARY 1950. ALBATROSS III - 30.

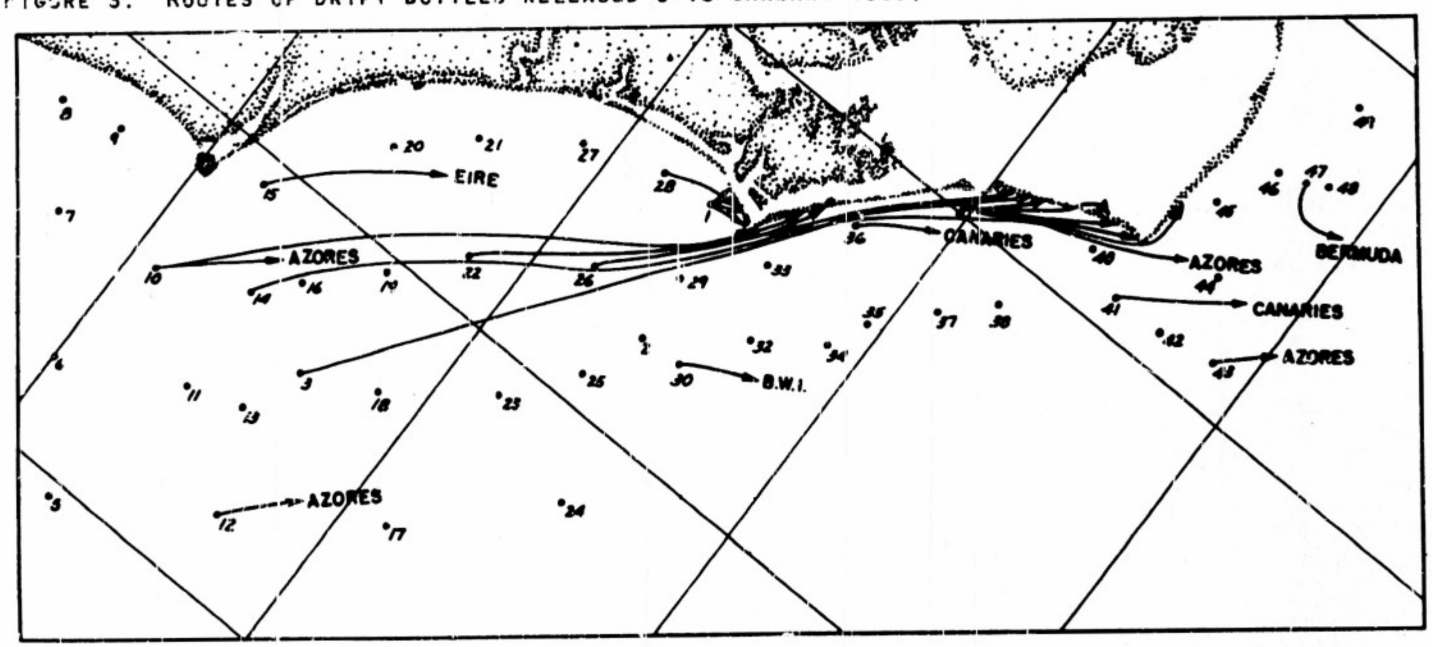

FIGURE 4. ROUTES OF DRIFT BOTTLES RELEASED 25 FEBRUARY - 4 MARCH 1950. ALBATROSS III - 32.

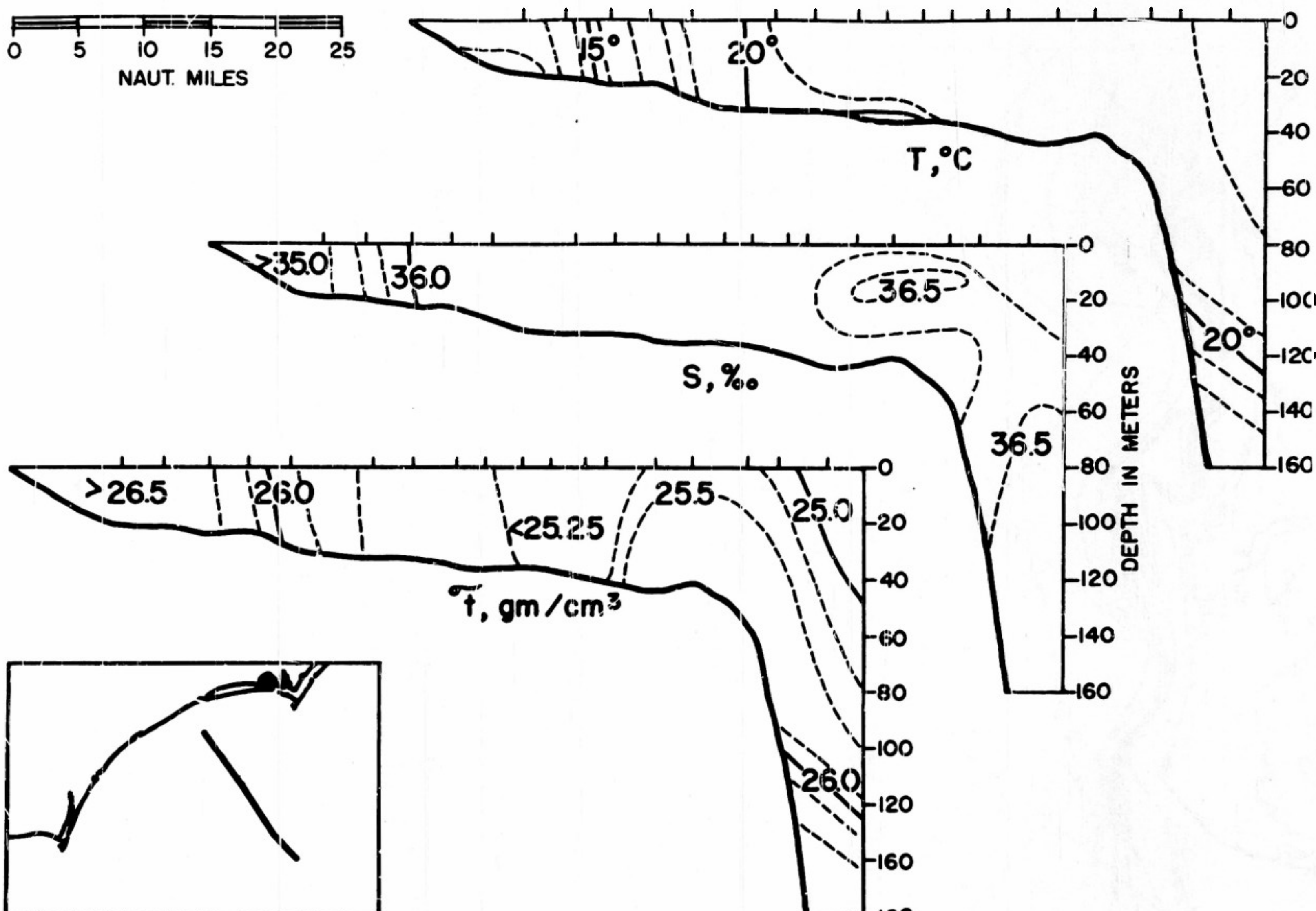

FIGURE 5. DISTRIBUTION OF TEMPERATURE, SALINITY, AND DENSITY ACROSS A TYPICAL SECTION IN ONSLOW BAY, JANUARY 1950, ALBATROSS III - 30.

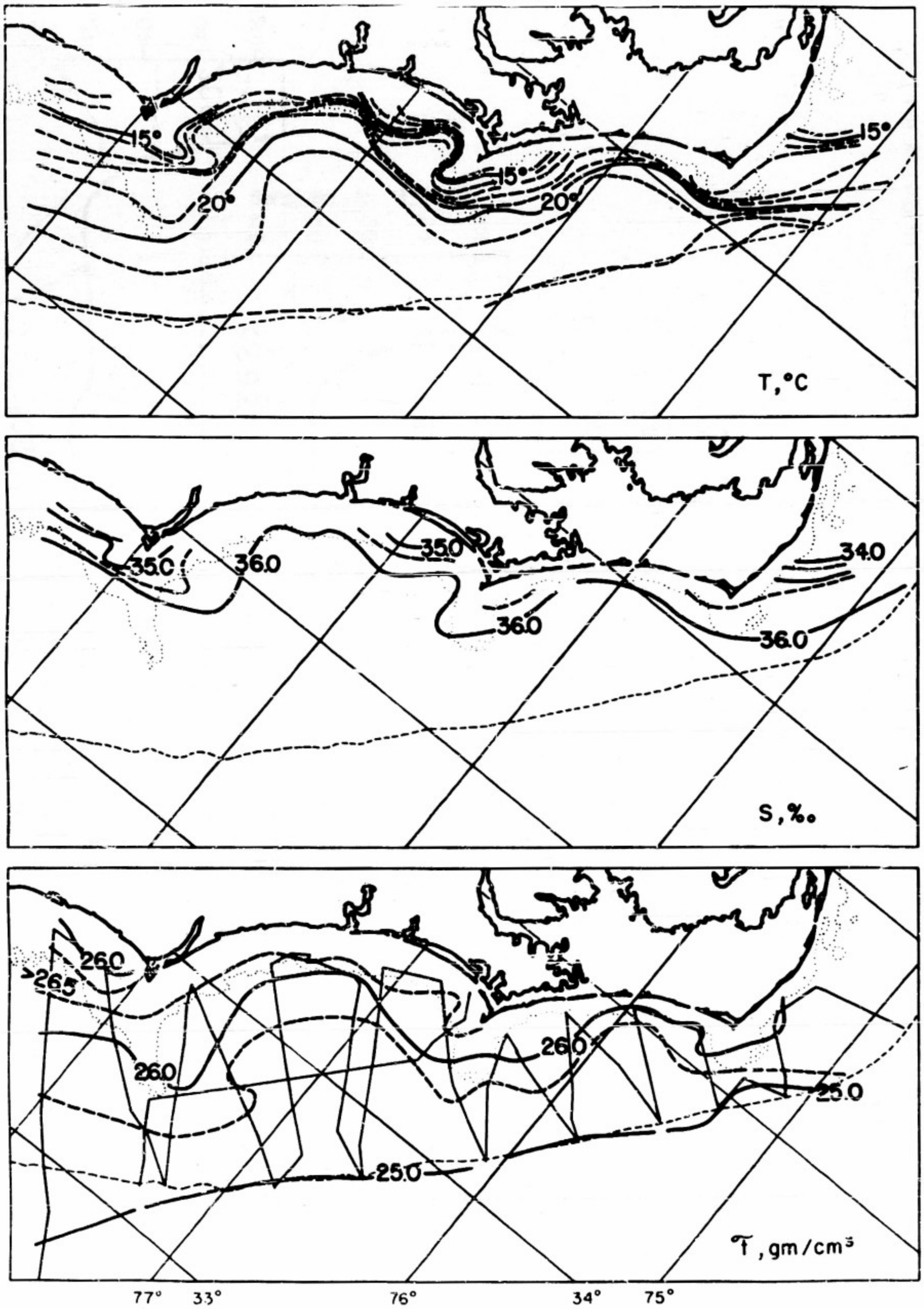

FIGURE 6. DISTRIBUTION OF SURFACE TEMPERATURE, SALINITY, AND DENSITY ON NORTH CAROLINA SHELF, JANUARY 1950, ALBATROSS III - 30.

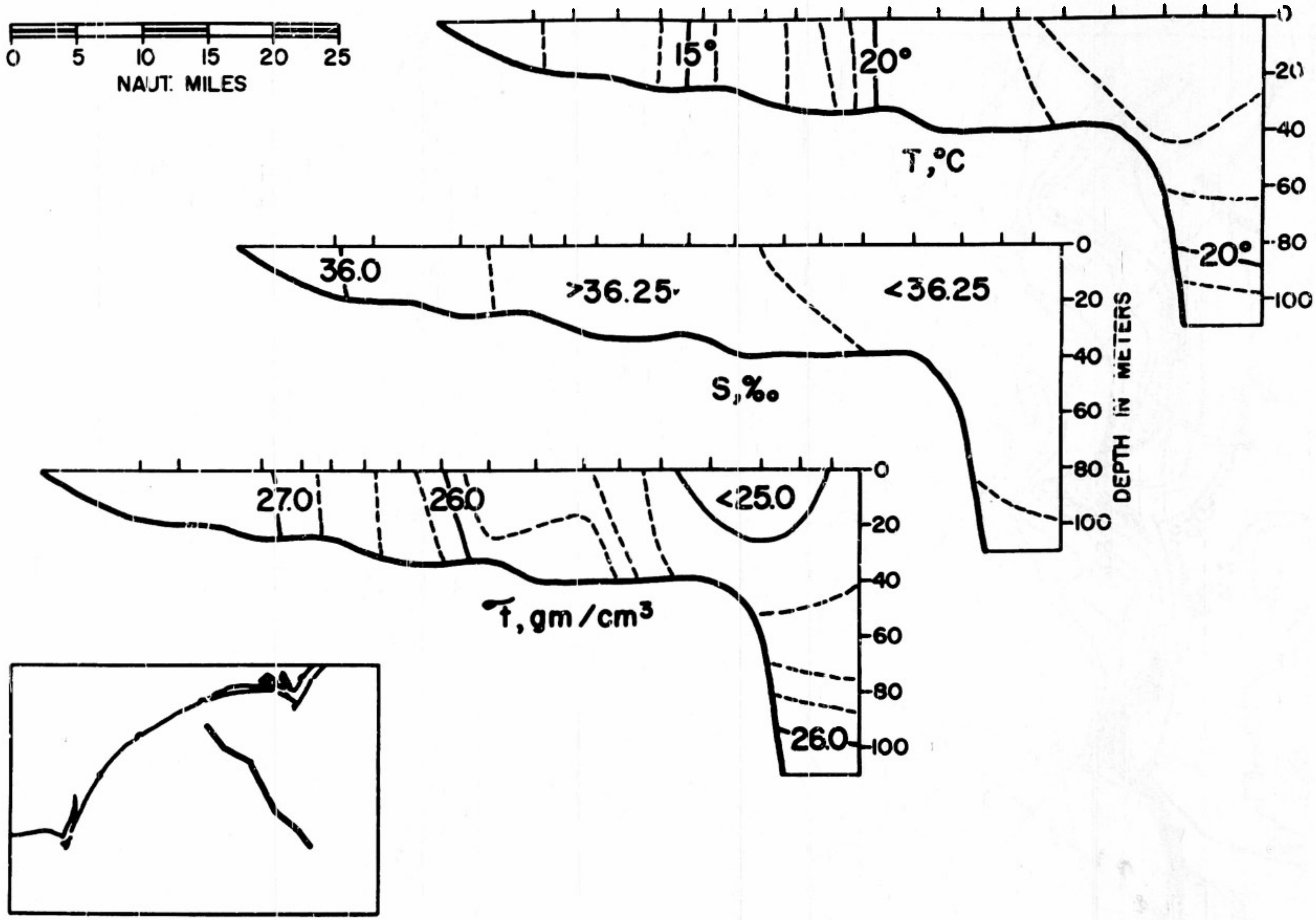

FIGURE 7. DISTRIBUTION OF TEMPERATURE, SALINITY, AND DENSITY ACROSS A TYPICAL SECTION IN ONSLOW BAY, FEBRUARY 1950. ALBATROSS III - 32.

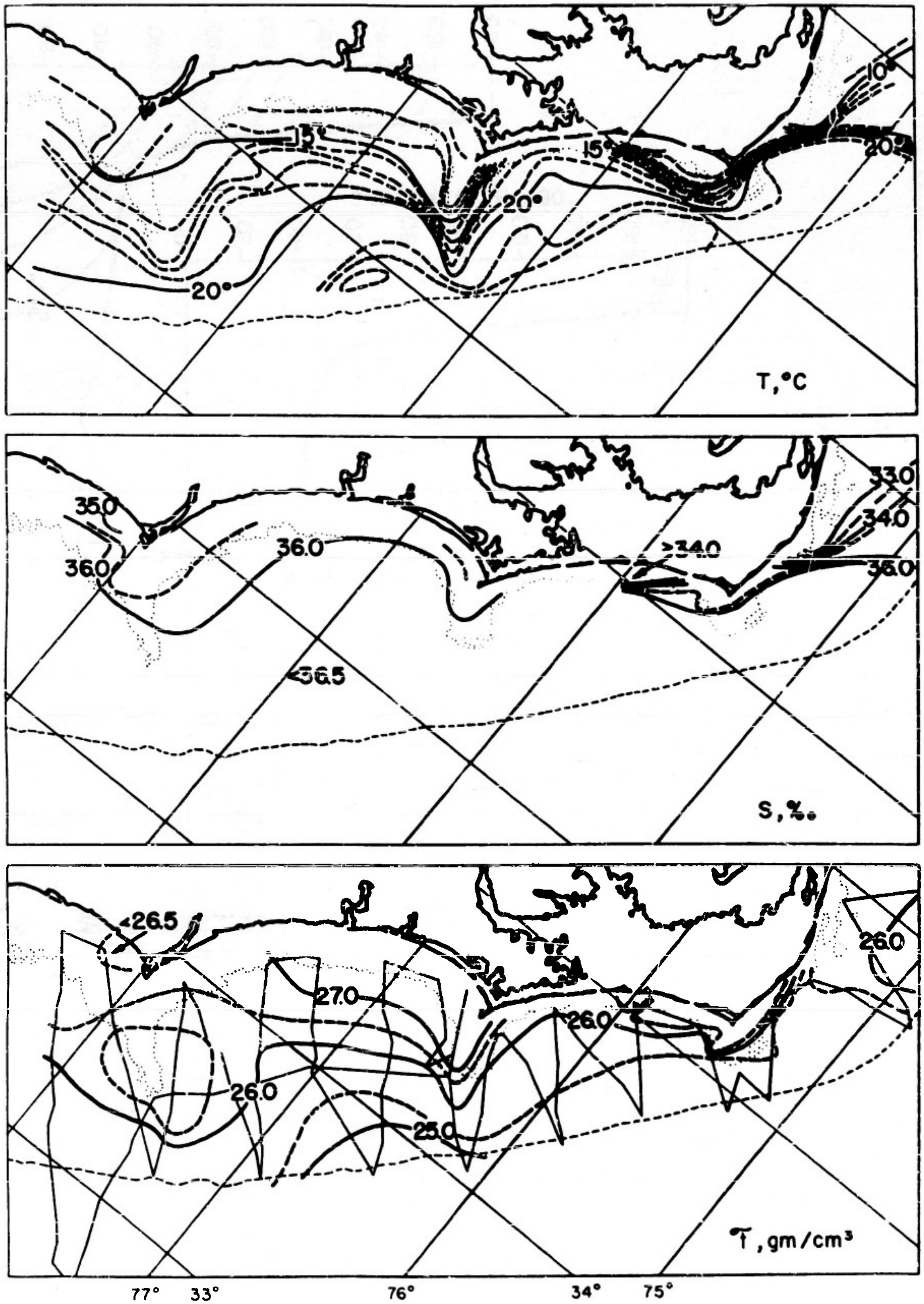

FIGURE 8. DISTRIBUTION OF SURFACE TEMPERATURE, SALINITY, AND DENSITY ON NORTH CAROLINA SHELF, FEBRUARY 1950, ALBATROSS III - 32.

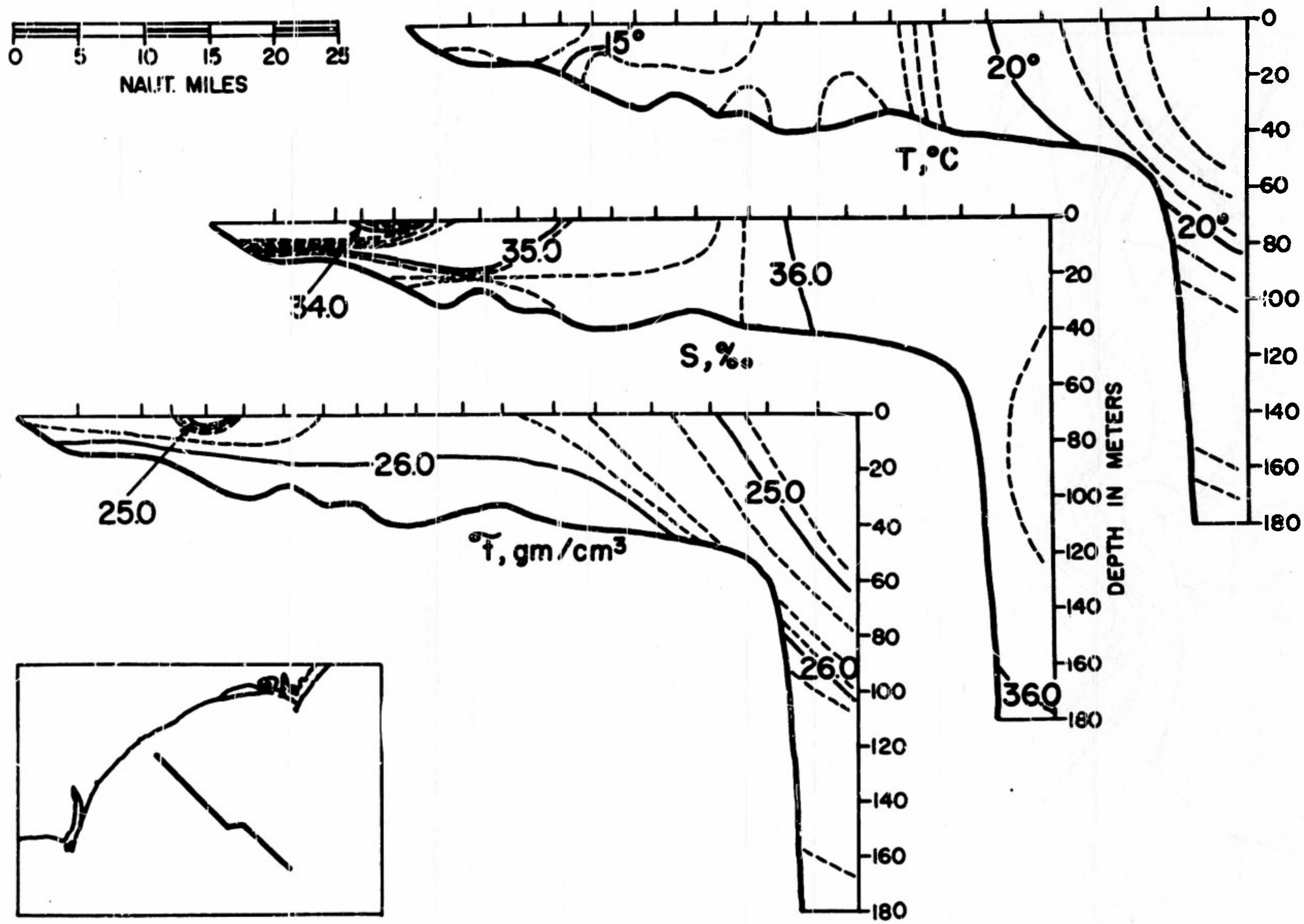

FIGURE 9. DISTRIBUTION OF TEMPERATURE, SALINITY, AND DENSITY ACROSS A TYPICAL SECTION IN ONSLOW BAY, MARCH 1948, RELIANCE - 4.

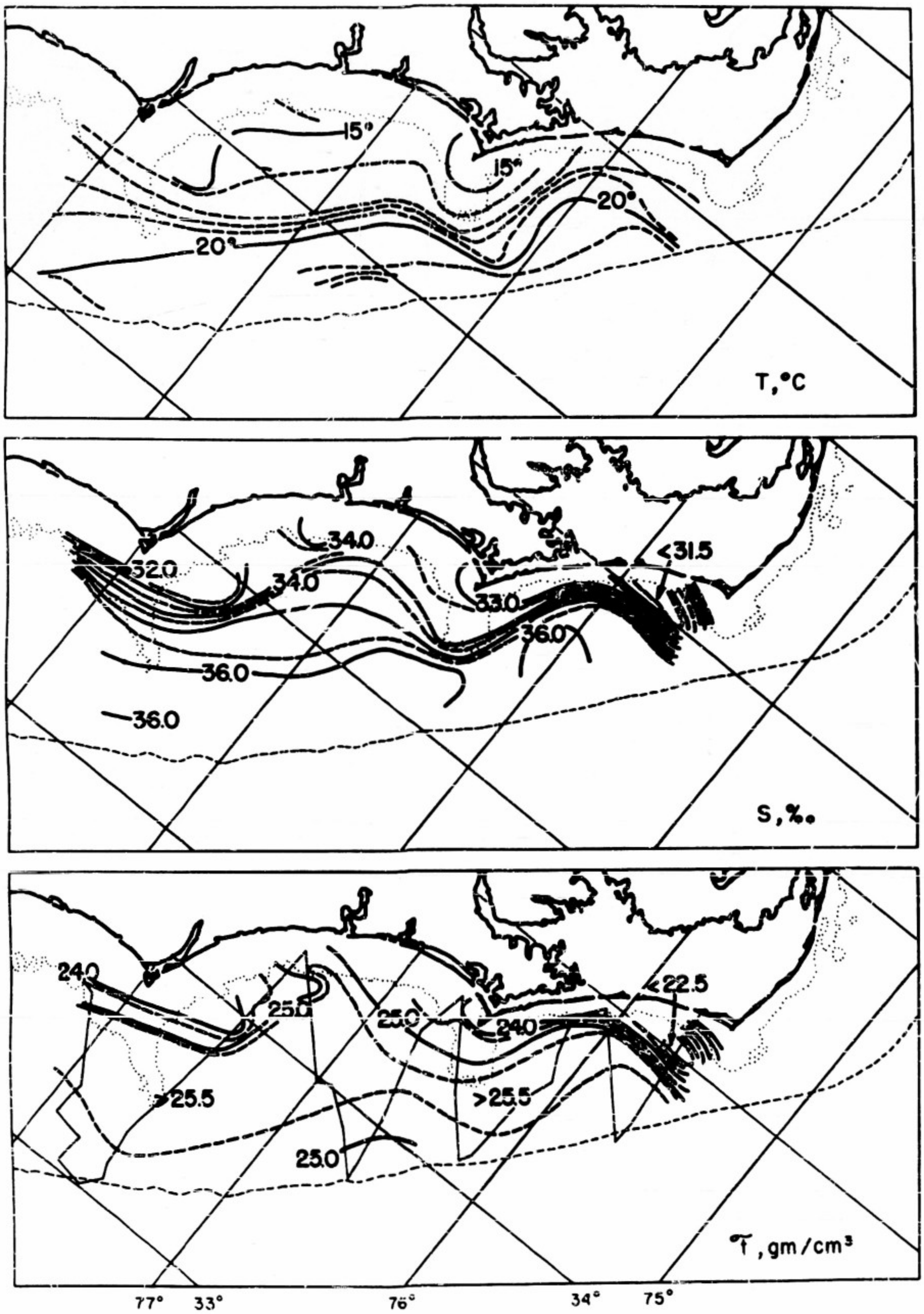

FIGURE 10. DISTRIBUTION OF SURFACE TEMPERATURE, SALINITY, AND DENSITY ON NORTH CAROLINA SHELF, MARCH 1948, RELIANCE - 4.

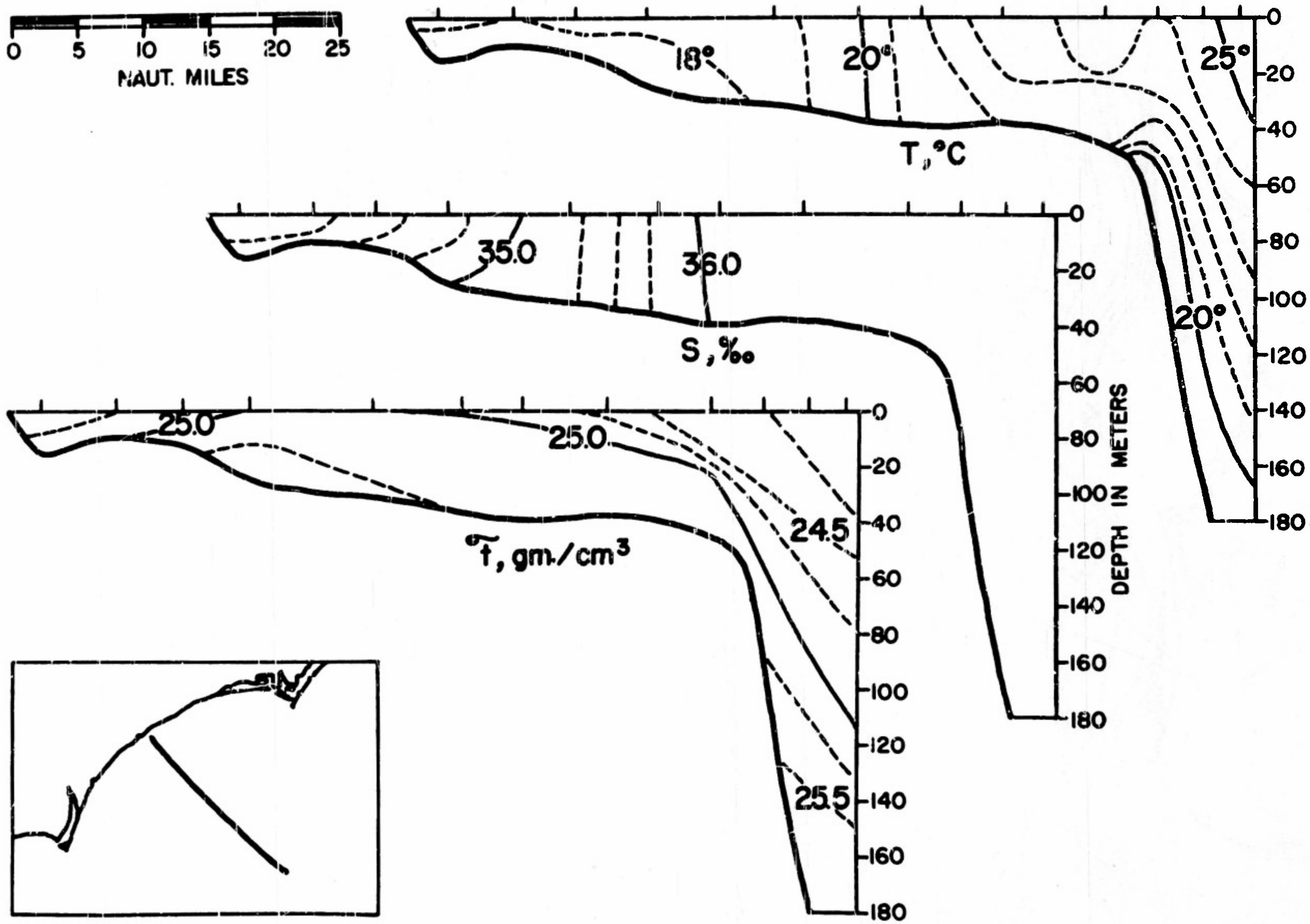

FIGURE 11. DISTRIBUTION OF TEMPERATURE, SALINITY, AND DENSITY ACROSS A TYPICAL SECTION IN ONSLOW BAY, APRIL 1948, RELIANCE - 6.

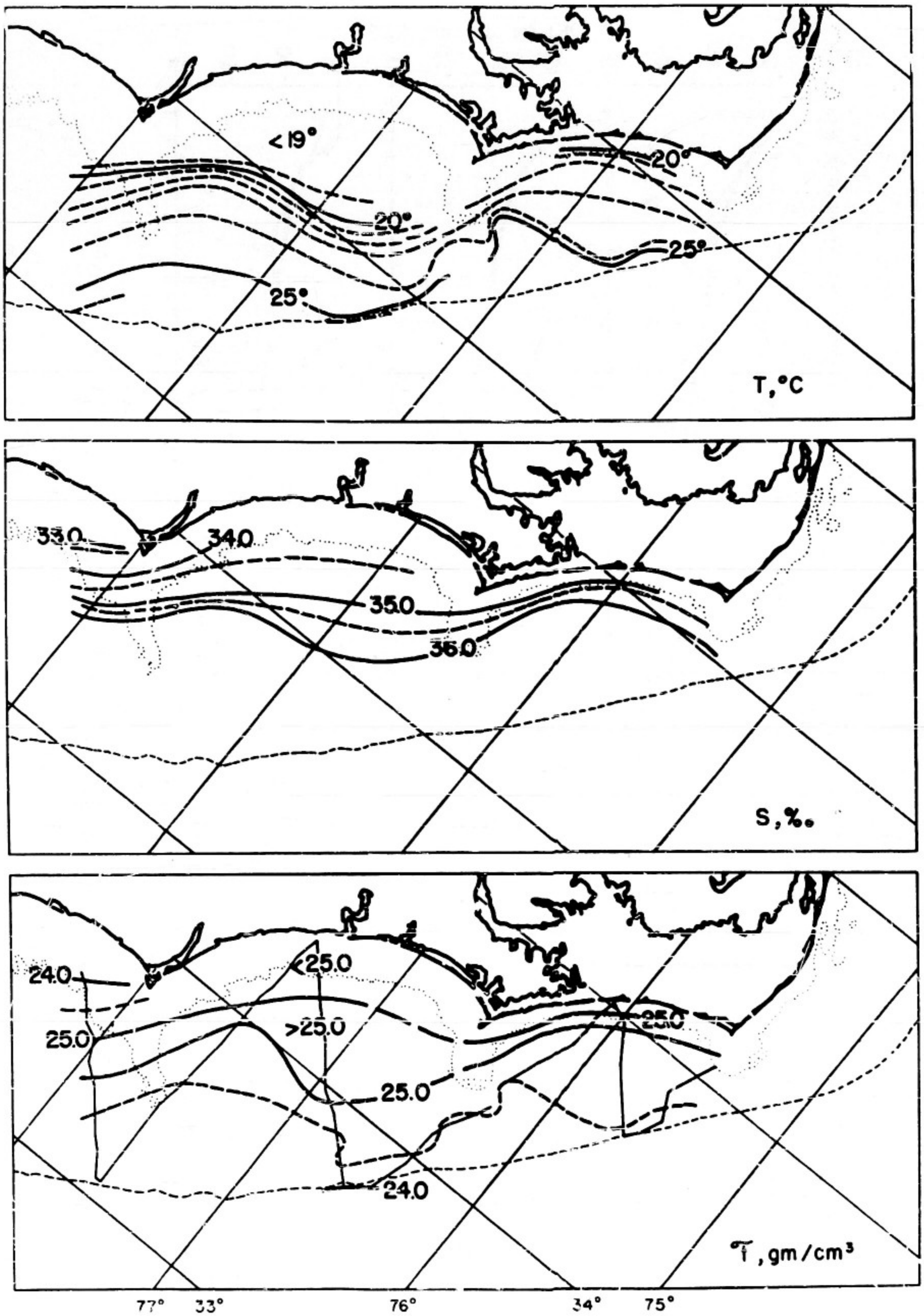

FIGURE 12. DISTRIBUTION OF SURFACE TEMPERATURE, SALINITY, AND DENSITY ON NORTH CAROLINA SHELF, APRIL 1948, RELIANCE - 6.

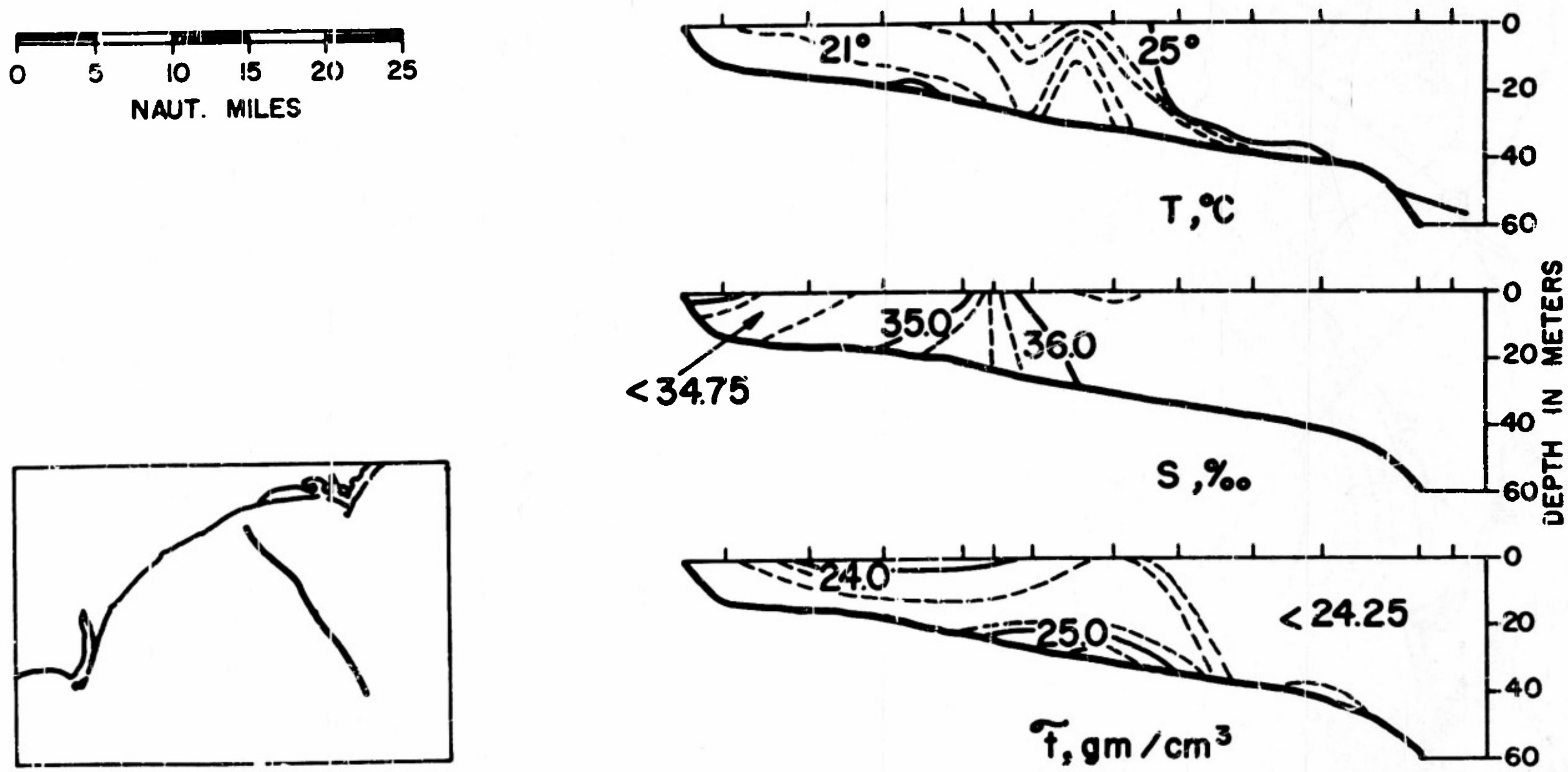

FIGURE 13. DISTRIBUTION OF TEMPERATURE, SALINITY, AND DENSITY ACROSS A TYPICAL SECTION IN ONSLOW BAY, MAY 1949, CARYN - 7.

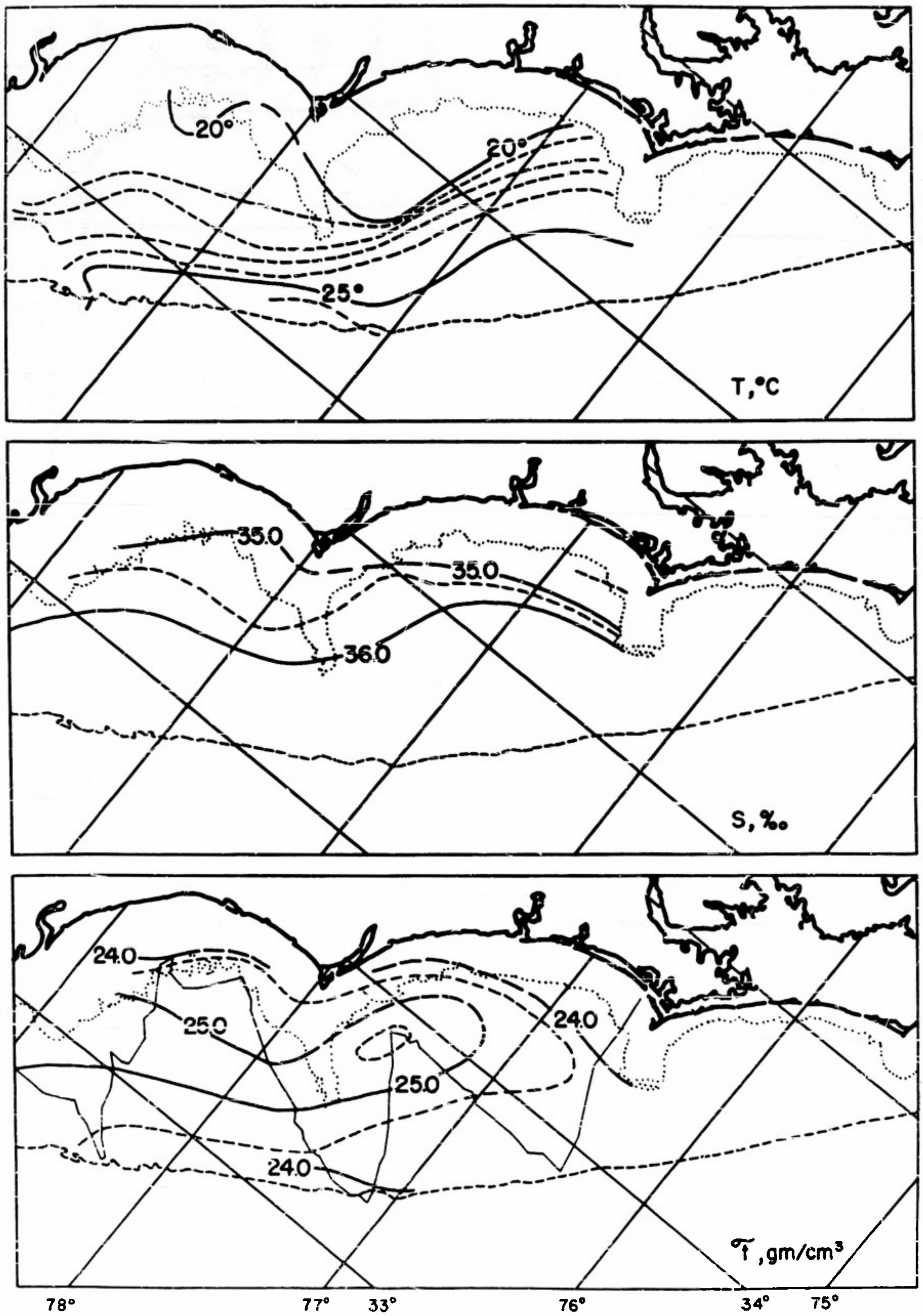

FIGURE 14. DISTRIBUTION OF SURFACE TEMPERATURE, SALINITY, AND DENSITY ON NORTH CAROLINA SHELF, MAY 1949, CARYN - 7.

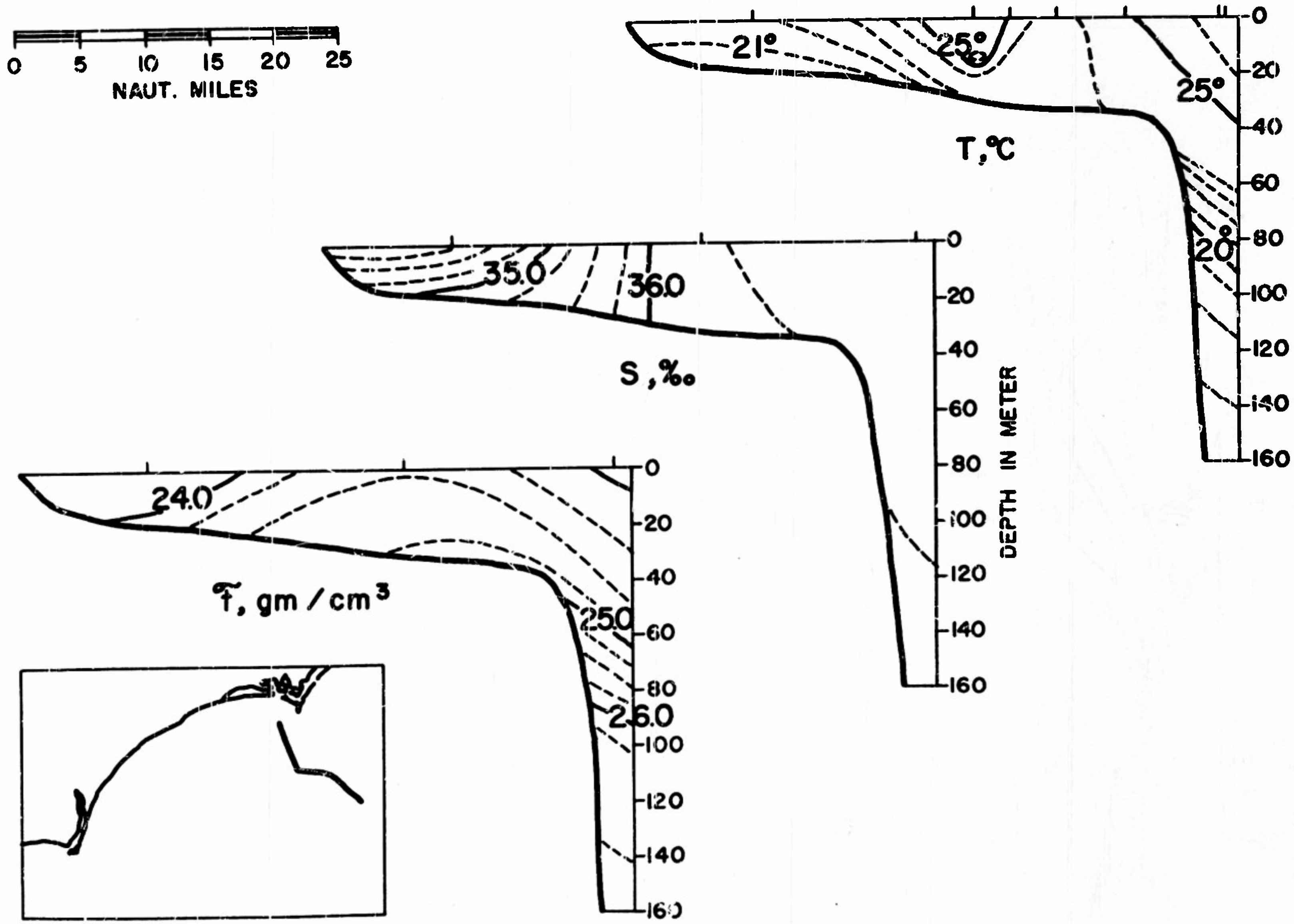

FIGURE 15. DISTRIBUTION OF TEMPERATURE, SALINITY, AND DENSITY ACROSS A TYPICAL SECTION IN ONSLOW BAY, MAY 1949, ALBATROSS III - 18, 19.

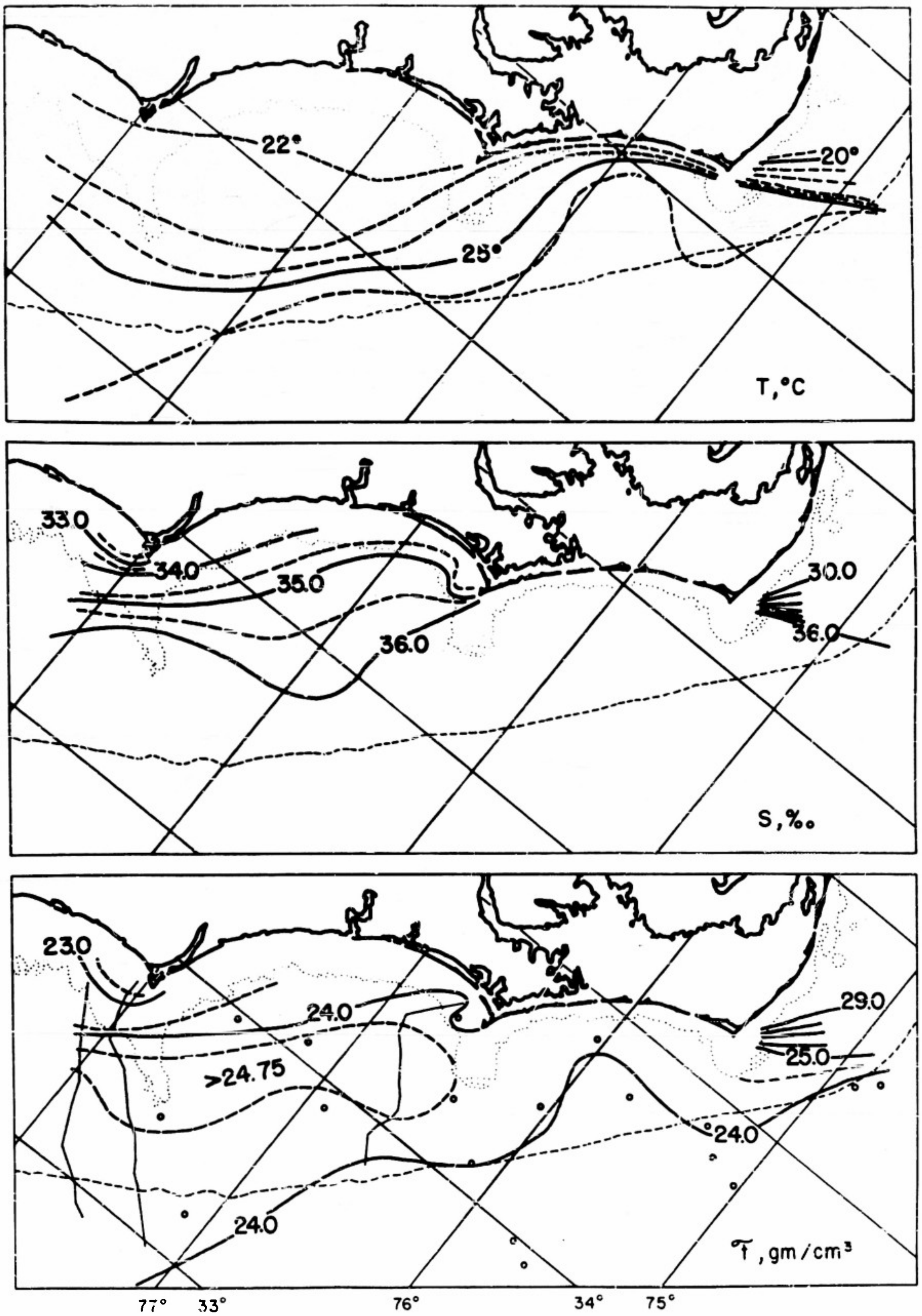

FIGURE 16. DISTRIBUTION OF SURFACE TEMPERATURE, SALINITY, AND DENSITY ON NORTH CAROLINA SHELF, MAY 1949. ALBATROSS III - 18, 19.

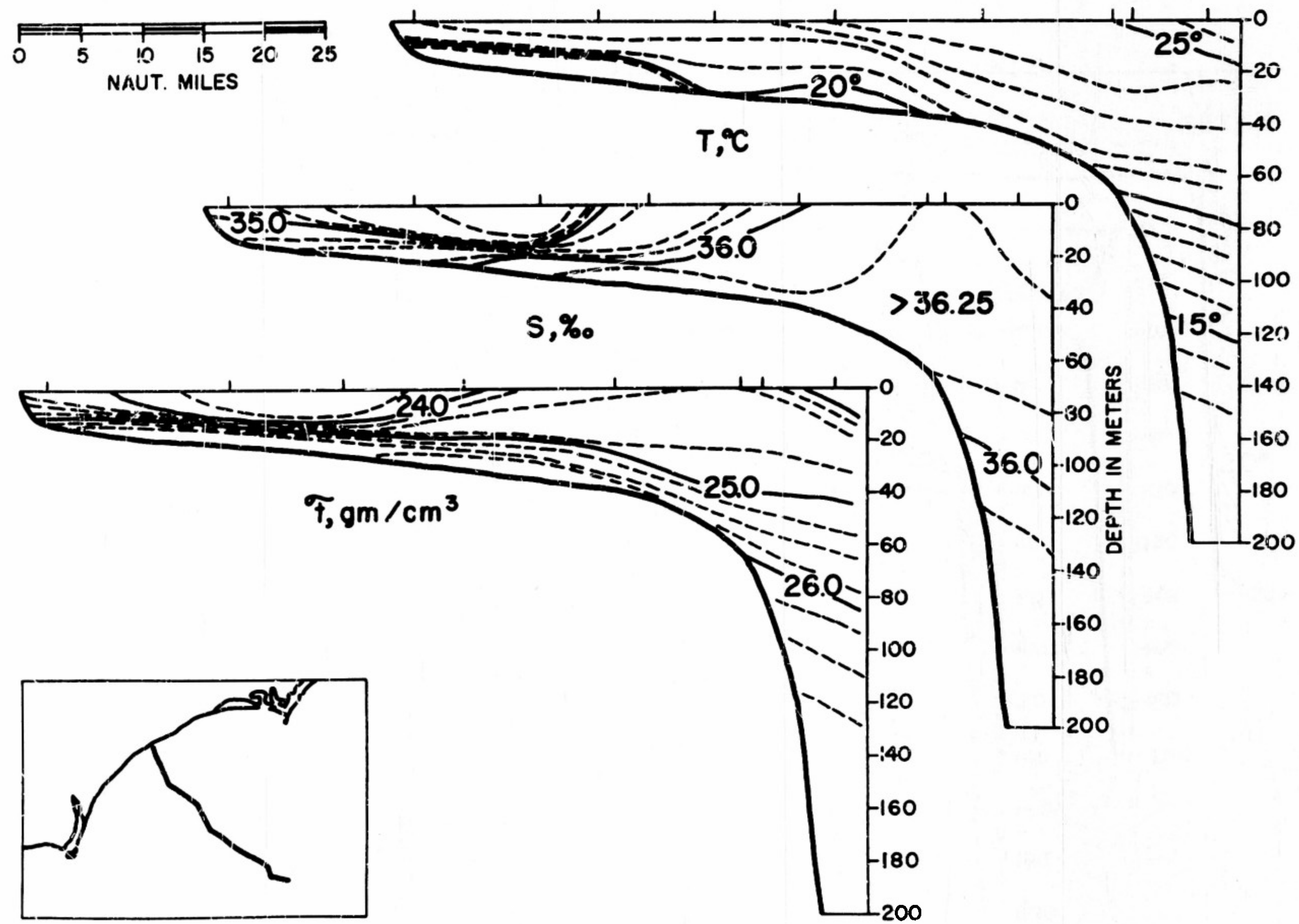

FIGURE 17. DISTRIBUTION OF TEMPERATURE, SALINITY, AND DENSITY ACROSS A TYPICAL SECTION IN ONSLOW BAY, MAY 1953, CARYN - 64.

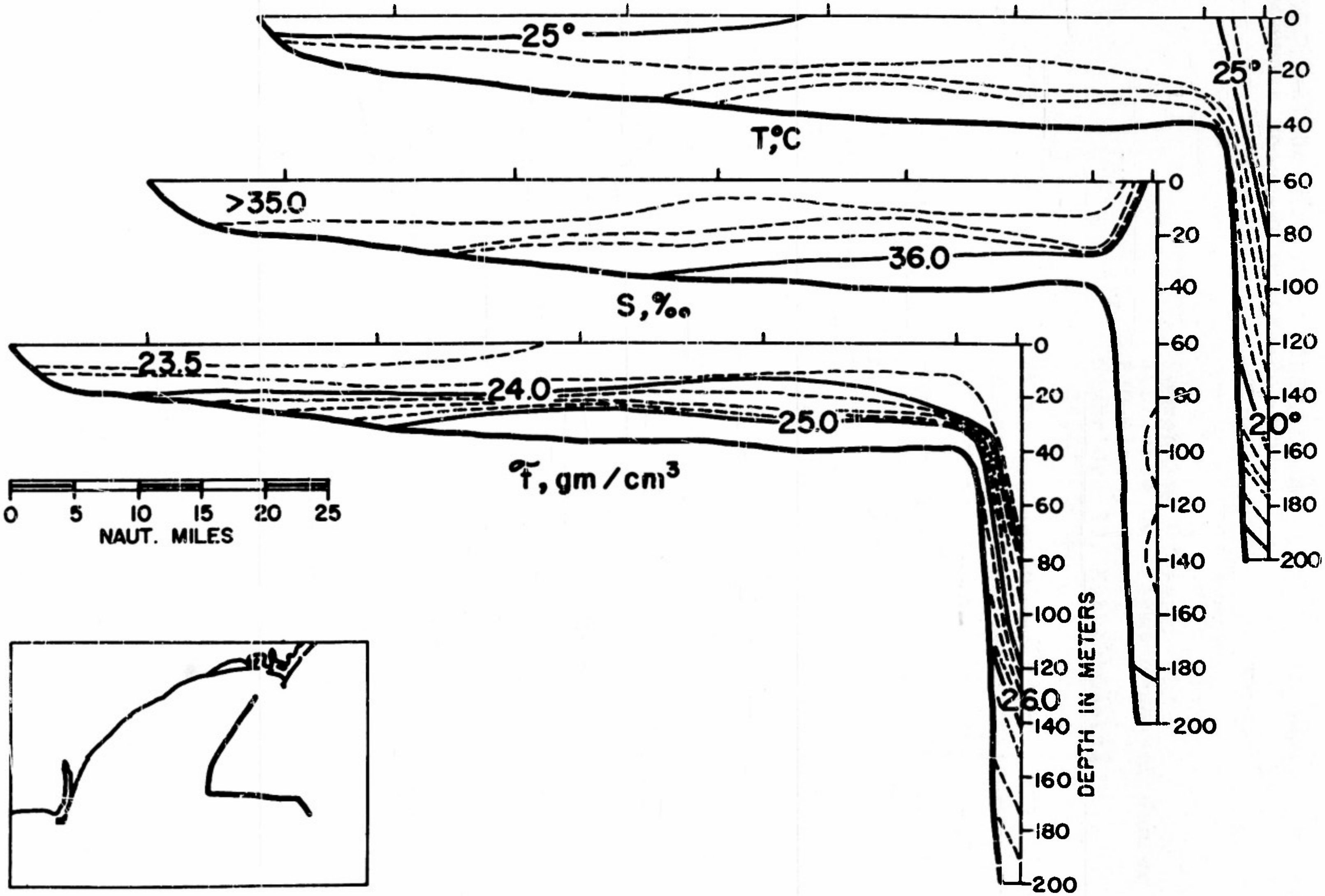

FIGURE 18. DISTRIBUTION OF TEMPERATURE, SALINITY, AND DENSITY ACROSS A TYPICAL SECTION IN ONSLOW BAY. JUNE 1953, CARYN - 64.

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